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Ultraminiature Quartz Crystal Units

Report No. 9

CONTRACT NO. DA36-039-SC-85348
FILE NO. 40658-PM-60-93-93 (4105)
DA PROJECT NO...3A99-15-001-02

FINAL REPORT

15 June 1960 to 14 October 1962

PREPARED FOR
U. S. ARMY ELECTRONIC RESEARCH
AND DEVELOPMENT LABORATORY
FORT MONMOUTH, NEW JERSEY

VICTOR ELECTRONIC SYSTEMS CO.
VICTOR COMPTOMETER CORPORATION
CHICAGO 48, ILLINOIS

ULTRAMINIATURE

QUARTZ CRYSTAL UNITS

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PROGRESS REPORT:	Final Report
PERIOD COVERED:	15 June 1960 - 14 October 1962
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BY:	VICTOR ELECTRONIC SYSTEMS CO. Victor Comptometer Corporation Chicago 18, Illinois

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TABLES AND FIGURES

PURPOSE

The purpose of this contract is to conduct theoretical and experimental investigations to determine the factors that limit the reduction in size of AT cut quartz crystal resonators, beginning with the frequency range and overtone number where the smallest possible size is likely to be attainable. The units shall be considered acceptable if the quality factor (Q) is [illegible],000 or above. Other specifications are standard, such as ±50 ppm over the temperature range -55° to +90°C. A usable drive power shall be recommended. Since the quality specification is in terms of Q, means for impedance transformation shall be investigated should such be necessary to enable the use of high resistance units in practical transistor circuits. Suitable methods of mounting, bonding, and sealing shall be devised.

ABSTRACT

Ultraminiature quartz resonators meeting the minimum Q requirement of 10,000 were fabricated at frequencies from below 9 MC to above 150 MC. Quartz plates as small as .100 inch in diameter gave satisfactory results over most of this frequency range. Contouring was necessary below 25 MC, but plane-parallel plates proved satisfactory above this frequency.

Both ceramic and glass enclosures were developed for these resonators. The overall volume of these enclosures was less than .002 cubic inches. Metal holders obtained from a commercial source were also used. These holders had a volume of approximately .006 cubic inches.

PUBLICATIONS, REPORTS, LECTURES AND CONFERENCES

First Monthly Letter Report -- for period
15 June 1960 to 14 July 1960

Second Monthly Letter Report -- for period
15 July to 14 August 1960

Third Monthly Letter Report -- for period
15 August to 14 September 1960

First Quarterly Progress Report -- for period
15 June to 15 September 1960

Fourth Monthly Letter Report -- for period
15 September to 14 October 1960

Fifth Monthly Letter Report -- for period
15 October to 14 November 1960

Sixth Monthly Letter Report -- for period
15 November to 14 December 1960

Second Quarterly Progress Report -- for period
15 September to 14 December 1960

Seventh Monthly Letter Report -- for period
15 December 1960 to 14 January 1961

Eighth Monthly Letter Report -- for period
15 January to 14 February 1961

Ninth Monthly Letter Report -- for period
15 February to 14 March 1961

Third Quarterly Progress Report -- for period
15 December 1960 to 14 March 1961

Tenth Monthly Letter Report -- for period
15 March to 14 April 1961

Eleventh Monthly Letter Report -- for period
15 April 1961 to 14 May 1961

Twelfth Monthly Letter Report -- for period
15 May 1961 to 14 June 1961

Fourth Quarterly Progress Report -- for period
15 March to 14 June 1961

Thirteenth Monthly Letter Report -- for period
15 June to 14 July 1961

Fourteenth Monthly Letter Report -- for period
15 July to 14 August 1961

Fifteenth Monthly Letter Report -- for period
15 August to 14 September 1961

Fifth Quarterly Progress Report -- for period
15 June to 14 September 1961

Sixteenth Monthly Letter Report -- for period
15 September to 14 October 1961

Seventeenth Monthly Letter Report -- for period
15 October to 14 November 1961

Eighteenth Monthly Letter Report -- for period
15 November to 14 December 1961

Sixth Quarterly Progress Report -- for period
15 October to 14 December 1961

Nineteenth Monthly Letter Report -- for period
15 December 1961 to 14 January 1962

Twentieth Monthly Letter Report -- for period
15 January to 14 February 1962

Twenty-first Monthly Letter Report -- for period
15 February to 14 March 1962

Seventh Quarterly Progress Report -- for period
15 December to 14 March 1962

Twenty-second Monthly Letter Report -- for period
15 March to 14 April 1962

Twenty-third Monthly Letter Report -- for period
15 April to 14 May 1962.

Twenty-fourth Monthly Letter Report -- for period
15 May to 14 June 1962

CONFERENCES

On the 8th of July 1960, Mr. Cortright and Mr. Tyler of Union Thermoelectric conferred with Dr. Guttwein of the U. S. Army Signal Research and Development Agency.

The 11th of July 1960 Dr. Guttwein and Mr. Stanley visited the Niles plant of Union Thermoelectric.

Mr. Cortright, Mr. Bennett, Mr. Tyler, Mr. Lavan, and Mr. Deininger of Union Thermoelectric conferred with Mr. Marvin Bernstein, project engineer for this contract, on 8 December 1960. Mr. Bernstein took back with him preliminary sample units which had been fabricated to represent current thinking.

No conferences were held during the second quarter.

On the 12th of May 1961, Mr. Marvin Bernstein and Dr. Guttwein of the Army Signal Research and Development Agency conferred with Messrs. Cortright, Tyler, Bennett, Brumbach, and Stringe of Union. A sample crystal unit, of the type contemplated for shipment in June, was given to Mr. Bernstein.

The 26th of July, Mr. Marvin Bernstein and Mr. Pat Mulvahill of the Army Signal Research and Development Laboratory conferred with Messrs. Cortright, Chalker, and Leide of Union Thermoelectric.

There were no conferences during the 6th quarter.

Dr. E. A. Gerber of the U. S. Army Signal Research & Development Laboratory conferred with Messrs. E. A. Roberts, R. P. Chalker, L. A. Tyler, and J. W. Stringe of Victor Electronic Systems Company.

The 30th of April 1962 Messrs. E. A. Roberts and R. P. Chalker of Victor Electronics Systems Company conferred with Dr. G. K. Guttwein, Messrs. Marvin Bernstein, and Joseph Stanley of the U. S. Army Signal Research and Development Laboratory.

FACTUAL DATA

INTRODUCTION

The current trend toward miniaturization of electronic equipment has resulted in a demand for quartz resonators of smaller and smaller size. The goal of this program was to determine how small a quartz resonator could be and still permit its use as a practical frequency controlling element.

The principal characteristic which limits a resonator's ability to control the frequency of an oscillator is the ratio of its motional reactance to its equivalent resistance. This is the quality factor Q. It was decided that a minimum Q value of 10,000 was necessary in order for the resonator to be effective in controlling frequency. This value was chosen as the principal performance criterion for the evaluation of resonators developed on this program.

The limit to which a quartz resonator can be miniaturized will be that size at which it is no longer possible to achieve the required performance characteristics. It would be most desirable to have sufficient information to be able to predict the performance characteristics of a resonator merely by specifying its physical dimensions, overtone order, and resonant frequency. This would allow one to make the optimum choice of physical parameters for any given resonator application. At the start of the program an attempt was made to approach the problem in this manner. Basically, it was assumed that the motional parameters of an AT type resonator could be

expressed as functions of four independent physical parameters, namely: plate diameter, electrode diameter, overtone order, and resonant frequency. The approach would be to hold three of these independent variables constant and determine the motional resistance, reactance, and Q as functions of the other variable. The disadvantage of this approach is that a considerable quantity of data is needed before useful results can be obtained. It was, therefore, decided to abandon this "fundamental" approach in favor of a more direct "cut and try" method.

After preliminary experiments with various plate sizes down to .070 inches in diameter, it became apparent that reducing the plate size below .100 inches would not result in a sufficiently smaller crystal unit to justify the accompanying degradation of performance. For this reason, further investigation was limited to resonator plates of this diameter or larger. This decision somewhat changed the original goal of the program from the determination of the smallest size resonator which could meet the Q requirement to the development of resonators of this particular size. In addition to developing fabrication techniques and a suitable enclosure for the resonator, it was felt that the following questions should be answered:

(1) Over what frequency range can a Q value of 10,000 or greater be achieved with a .100 inch uncontoured plate.

(2) Which overtone order will provide the best performance over this frequency range.

(3) What is the optimum electrode size with respect to achieving maximum Q or minimum resistance.

(4) Can the frequency range be extended or performance improved by employing spherically contoured plates.

EXPERIMENTAL RESULTS

Uncontoured Plates

Plane-parallel plates, .100 inch in diameter, were fabricated with various thicknesses ranging from .0065 inches to .0020 inches. This represents a fundamental frequency range of 10 MC to 32 MC. In excess of 200 uncontoured quartz resonators were fabricated. A summary of the performance characteristics of this is given in Table 1. The values listed are those for the units exhibiting the highest Q values for that particular frequency and electrode diameter. The values listed for the third and fifth overtones represent the highest Q values obtained for that particular overtone, and in some cases, do not refer to the same individual resonators listed in the fundamental mode column.

The highest Q values obtained with .100 inch uncontoured plates are plotted in Figure 1 as a function of resonant frequency. The Q requirement of 10,000 was met over the frequency range from 25 MC to more than 150 MC. Judging from this data, fundamental mode resonators of this size are only satisfactory above 25 MC. Since it is quite difficult to produce AT type resonators with fundamental frequencies above 30 MC, the frequency range that can be satisfactorily covered with fundamental mode resonators is quite small, at least without contouring.

Resonators operating on the third overtone exceeded the Q requirements above 36 MC. Those operating on the fifth mode were satis-

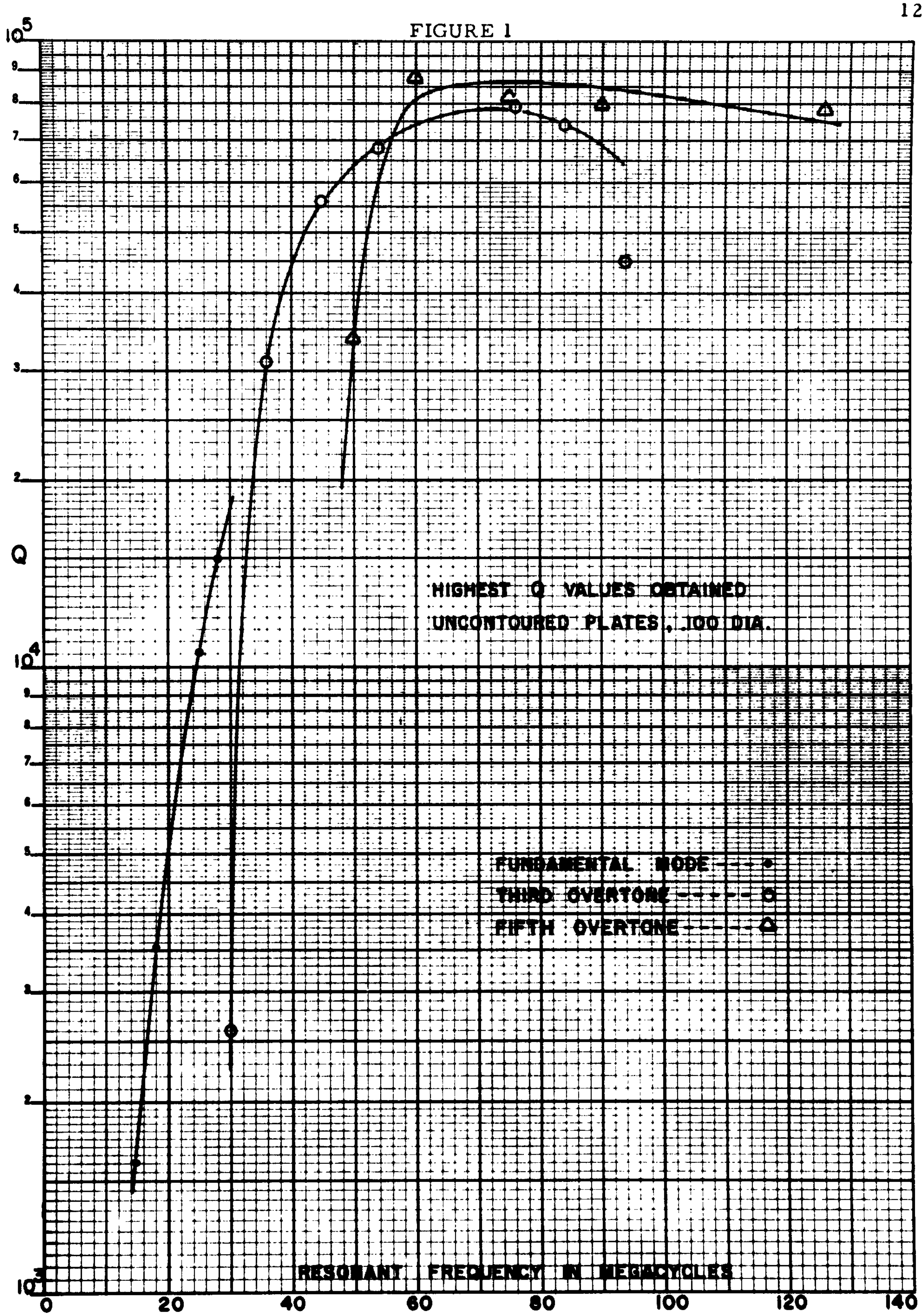
TABLE 1

UNCONTOURED PLATES

.100" Diameter, Polished

Electrode' Dia. (In.)	f_1 (MC)	R_1 (Ohms)	Q_1	f_3 (MC)	R_3 (Ohms)	Q_3	f_5 (MC)	R_5 (Ohms)	Q_5
.060	10	No Oscillation		30	3500	2,600	50	1200	34,000
.050	12	No Oscillation		36	1300	28,000	60	850	89,000
.060	12	No Oscillation		36	650	31,000	60	1200	78,000
.070	12	No Oscillation		36	800	28,000	60	450	76,000
.080	12	No Oscillation		36	550	25,000	60	400	51,000
.050	15	3000	1400	45	500	31,000	75	350	75,000
.060	15	2500	1500	45	350	56,000	75	300	83,000
.070	15	2500	1500	45	325	36,000	75	300	64,000
.080	15	2500	1600	45	450	24,000	75	450	66,000
.050	18	800	3000	54	140	68,000	90	325	62,000
.060	18	650	3500	54	250	58,000	90	275	79,000
.070	18	500	2800	54	75	58,000	90	100	72,000
.070	20	700	2200	60	140	32,000	100	300	29,000
.080	20	800	1100	60	130	22,000	100	600	15,000
.060	25	110	11000	76	35	80,000	126	90	79,000
.060	28	80	15000	84	60	74,000	142	75	66,000
.060	30	60	10000	90	180	16,000			
.060	32	55	11000	94	125	45,000	157		36,000

FIGURE 1

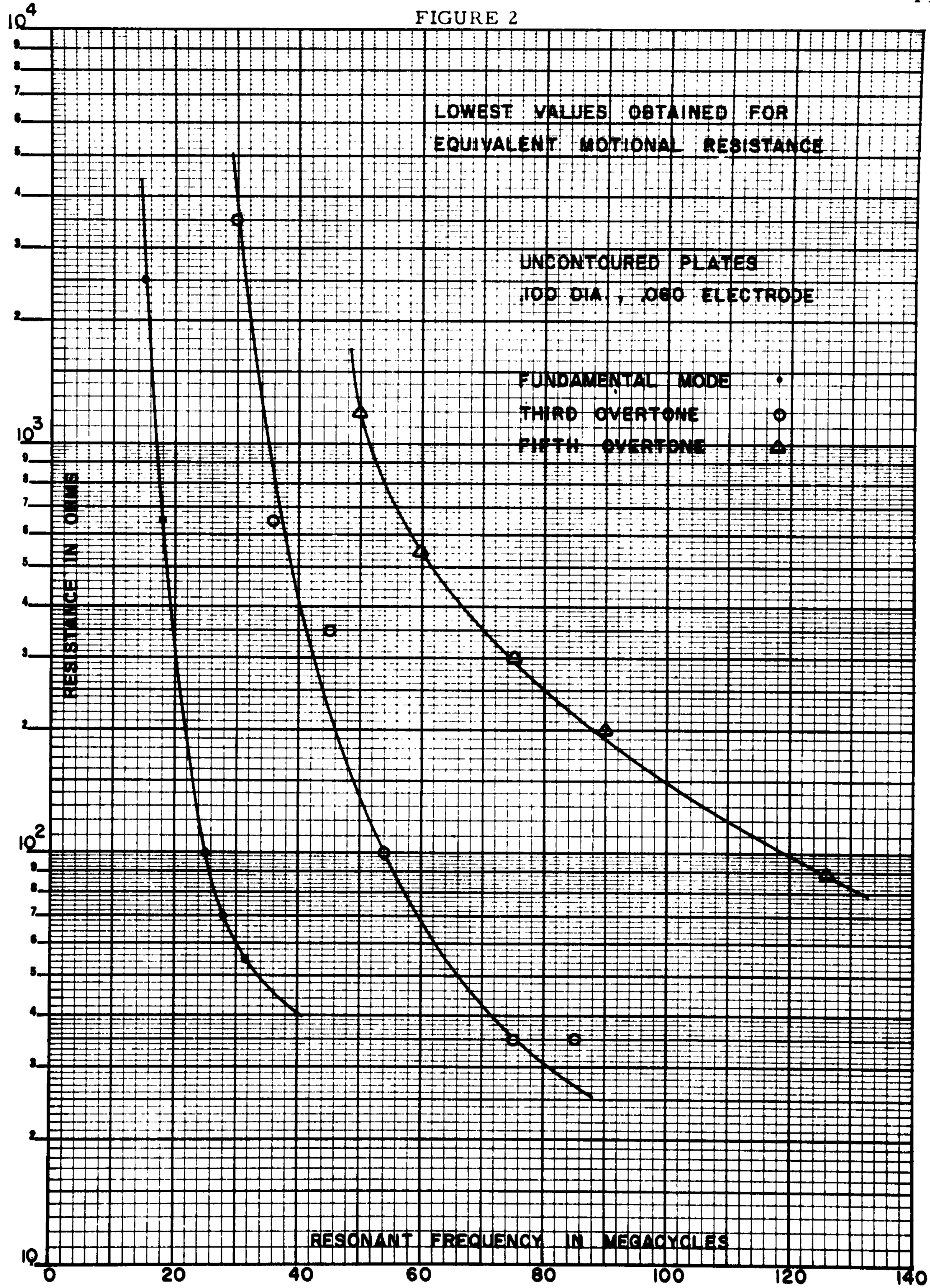

HIGHEST Q VALUES OBTAINED
UNCONTOURED PLATES, .100 DIA.
FUNDAMENTAL MODE ---- •
THIRD OVERTONE ----- O
FIFTH OVERTONE ----- △
Q
RESONANT FREQUENCY IN MEGACYCLES
10^5
10^4
10^3
0
20
40
60
80
100
120
140

factory at all frequencies tested. Fifth mode units had slightly higher Q values, at frequencies above 60 MC, than those operating on the third overtone. The difference in ultimate Q values between the third and fifth overtone is probably not significant. It may merely represent a measurement inaccuracy caused by the affect of the considerable difference in the impedance values of the two overtones. Another possible factor which would tend to favor the higher overtone order is the fact, that for a given operating frequency, a third mode resonator is thinner than a fifth mode and thus is less likely to have its surfaces accurately parallel. This difficulty in achieving parallelism on very thin plates may explain the drop in Q values at the higher frequencies for all three modes as shown by the data in Table 1.

Experiments with various electrode sizes (.050 to .080 inches) on .100 diameter plates indicated no consistent effect on Q values. Any variation in Q due to the electrode size, apparently, is less than the individual variations among units of the same dimensions, at least within the range of electrode sizes tested.

The motional resistance values obtained with .100 inch uncontoured plates are also listed in Table 1. The lowest values that were obtained with .060 inch electrodes are plotted in Figure 2 as a function of the resonant frequency. As to be expected, the motional resistance increases with overtone order. However, the variations in resistance due to different electrode

FIGURE 2


LOWEST VALUES OBTAINED FOR
EQUIVALENT MOTIONAL RESISTANCE
UNCONTOURED PLATES
.100 DIA. , .060 ELECTRODE
FUNDAMENTAL MODE
THIRD OVERTONE
FIFTH OVERTONE
RESISTANCE IN OHMS
RESONANT FREQUENCY IN MEGACYCLES
10^4
10^3
10^2
10
0
20
40
60
80
100
120
140

sizes, as indicated by the data in Table 1, is not nearly as regular as would ordinarily be expected. To a first approximation, the resistance of a resonator of given plate dimensions should be inversely proportional to the square of the electrode diameter. The failure of the larger electrodes to produce consistently lower resistance values is probably due to the overriding effect of the relatively large amount of damping by the mounting supports.

Ultraminiature resonators were found to exhibit the characteristic AT type frequency-temperature curves, as expected. No special effort was made to establish optimum ZZ' orientation angles for these resonators since the values would be the same as those required for larger plates of the same diameter to thickness ratio and this information is widely available.

Although the results listed in Table 1 were obtained with polished plates, a polished surface is not necessary except at high frequencies. A number of unpolished resonators were tested during earlier experiments with good results up to 60 MC. There is no evidence that surface finish requirements are any more stringent for ultraminiature resonators than for larger plates of the same frequency.

Contoured Plates

Below 25 MC, .100 inch uncontoured plates did not meet the minimum Q requirement of 10,000. In order to extend the frequency range

downward, experiments were conducted with spherically contoured plates. Both plano-convex and bi-convex designs were tested. The results obtained are listed in Table 2. The resistance values of the plano-convex units below 10 MC were to high to permit the measurement of Q values with the instrumentation available, but they are considerably less than 10,000.

Figure 3 is a plot of the highest Q values obtained with .100 inch contoured plates. Values exceeding 10,000 were obtained between 9.4 and 22 MC. The reason for the drop in Q at the higher frequencies is not certain, but it is probably due to an unfortunate choice of curvature values. The time available did not permit a extensive investigation of various curvature values, but there is no reason to doubt that Q values above 10,000 could be achieved with contoured plates at frequencies considerably higher than 22 MC, although the fabrication problems would become increasingly difficult.

The lowest frequency at which a .100 inch contoured plate met the Q requirement was 9.4 MC. A lower frequency limit could probably be attained by employing a greater contouring curvature, but spherical laps of greater curvature than 40 diopters were not available at the time. Also, since a 40 diopter lap has a radius of curvature of only .522 inches, the contouring operation becomes quite difficult.

Since the ceramic and glass enclosures that were developed would not accept circular plates much larger than .100 inches in diameter,

TABLE 2

SPHERICALLY CONTOURED PLATES

.100" Diameter, .060" Electrodes

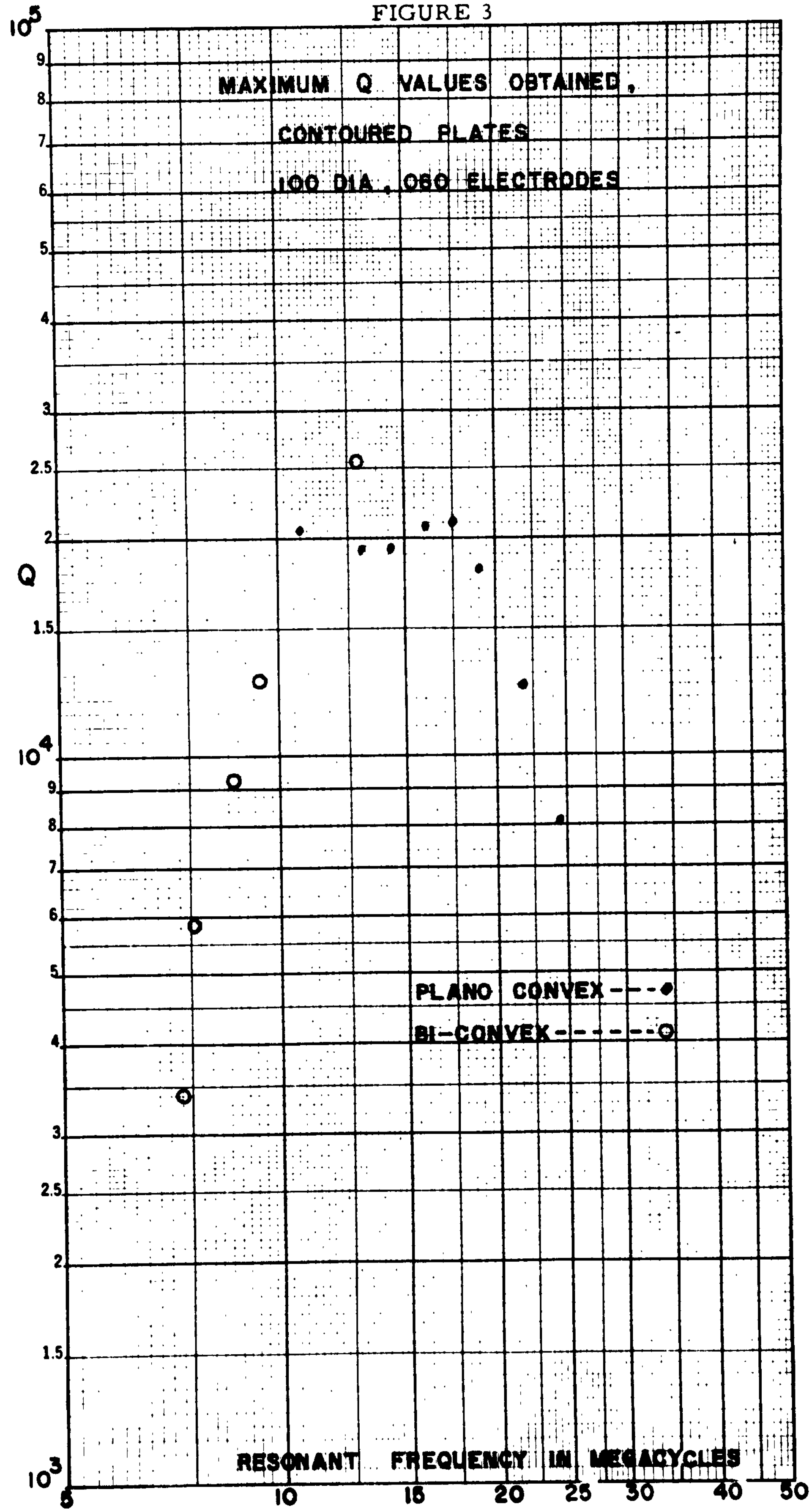
PLANO-CONVEX

Frequency (MC)	Curvature (diopters)	Resistance (Ohms)	Q
8.20	32	3500	
8.32	40	3000	
8.44	32	1000	
10.7	40	650	21,000
18.8	32	700	16,000
13.2	32	210	19,000
16.0	30	80	21,000
17.5	30	85	21,000
19.0	20	110	18,000
21.8	10	125	12,000
24.3	10	225	8,000

BI-CONVEX

Frequency (MC)	Curvature (diopters)	Resistance (Ohms)	Q
7.25	32	2500	3,400
7.42	32	2200	3,900
7.53	40	1800	5,800
8.55	32	700	7,600
8.63	40	700	9,200
9.45	40	900	13,000
11.02	40	1400	5,900
12.88	32	500	25,000

FIGURE 3


MAXIMUM Q VALUES OBTAINED,
CONTOURED PLATES
.100 DIA, .060 ELECTRODES
Q
PLANO CONVEX
BI-CONVEX
RESONANT FREQUENCY IN MEGACYCLES
10
15
20
25
30
40
50

it was decided to employ a "racetrack" shaped plate in an attempt to meet the Q specifications at lower frequencies. The plates had a diameter of .125 inch with flats ground parallel to Z'. The plate width in the X-direction was reduced to .100 inch to fit the enclosure dimensions. Results obtained with plano-convex and bi-convex resonators of these dimensions are shown in Table 3. The lower frequency limit of acceptable Q values has only been reduced slightly by the increase in plate dimensions. The frequency range could probably be reduced by contouring on higher curvature laps, but new contouring methods would be needed to produce the high curvatures.

TABLE 3

SPHERICALLY CONTOURED PLATES

.125" x .100", .080" Electrodes

PLANO-CONVEX

Frequency (MC)	Curvature (diopters)	Resistance (Ohms)	Q
8.53	32	3000	500
8.87	32	700	11,000
9.10	32	2500	1,500
10.58	32	350	19,000
11.11	32	275	19,000

BI-CONVEX

Frequency (MC)	Curvature (diopters)	Resistance (Ohms)	Q
6.51	32	2500	2,700
6.88	32	1200	3,700
8.73	32	400	16,000
8.80	32	425	17,000
8.90	32	450	25,000
10.50	32	275	21,000
11.0[illegible]	32	450	24,000

ENCLOSURE DESIGN

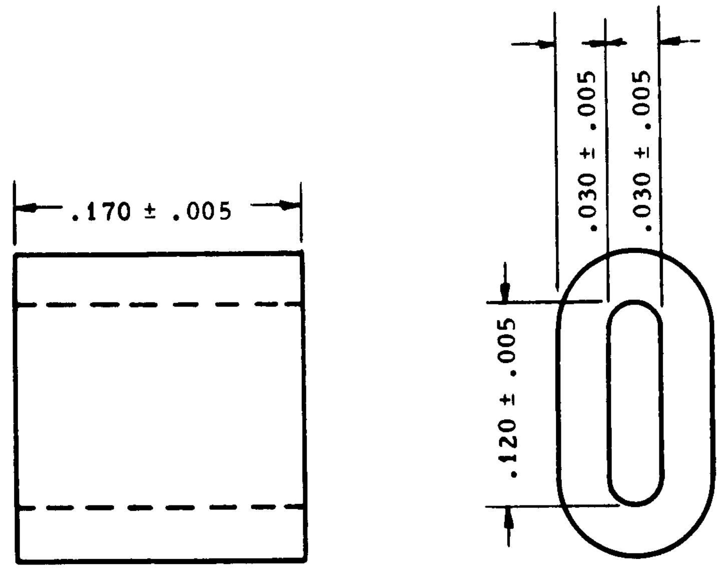
Practical limitations on the miniaturization of quartz crystal units are as much dependent on the enclosure design as on the resonator itself. Beyond a certain point, reducing the size of the resonator plate no longer results in a significant reduction in overall crystal unit volume. This is due, in part, to the fact that the wall thickness of the enclosure cannot be indefinitely reduced. An efficient enclosure design will have a minimum of unused space inside the holder and walls that are as thin as practicable. For relatively thin, circular plates, the shape which would result in the least volume for the crystal unit would be a cylindrical "pillbox" with an internal diameter only slightly greater than that of the quartz plate. A few experimental holders of this configuration were made, but the resonator performace proved unsatisfactory. A spacer type mounting was used employing concave metal electrodes of the same diameter as the quartz plate. The electrodes contacted the plate around its periphery, leaving an air gap in the center of the plate. Clamping the plate around its entire circumference apparently caused excessive damping of the vibration. The presence of the air gap would also increase the equivalent resistance of the resonator, but should not have affected its Q.

The spacer type mounting might prove satisfactory for ultraminiature resonators to be operated at very high frequencies, but in order to achieve satisfactory performance at the more widely used frequencies (below 100 MC), it was necessary to mount the crystal plate with as little

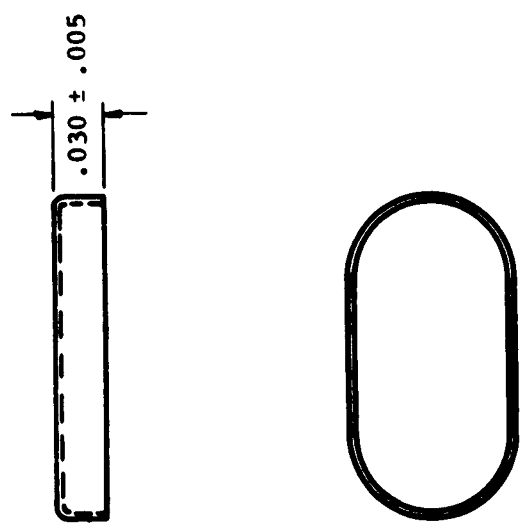
constraint as possible. For this reason it was decided to design the enclosure to employ wire mounted resonators. The configuration chosen is shown in Figure 4. The ceramic or glass part is fabricated in the form of tubing with an oval cross section and then cut to length. The end caps are formed from a sheet of .0035 inch silver in a punch press. The ceramic parts were fabricated by American Lava Company of high alumina ceramic (Alsimag 665). Their part number for this piece is E-61304. The glass enclosures are made of Type KG-12 glass and were fabricated by Hanibal Glass, Inc., Santa Anna, California.

The ceramic enclosures were tried first, primarily because a supplier of glass parts of these dimensions had not been found. Although the ceramic itself is quite suitable as a material for hermetically sealed enclosures, it is generally more difficult to metalize than glass. Glass also has an advantage in this enclosure design in that it simplifies positioning of the crystal plate.

Both ceramic and glass holders were sealed with solder, either with or without the end caps. Since the inside of the tubing is only .030 inches wide, solder readily bridges the opening in the end of the enclosure without any additional support. The end caps were added to give a somewhat more durable unit. In many cases, however, good hermetic seals were not achieved with these holders. One reason for this may be the necessity of performing the entire sealing operation in one step



CERAMIC OR GLASS HOLDER



SILVER END CAPS

FIGURE 4
Ultraminiature Holder Parts

rather than having a pinhole for the final seal-off.

As an alternative enclosure for ultraminiature resonators, metal holders of more conventional design were obtained from Howard Crystal Holders, Kansas City, Missouri, their Type HK-24. This holder is shown along with the ceramic and glass enclosures in Figure 5. In this photograph, the crystal units are shown ten times actual size.

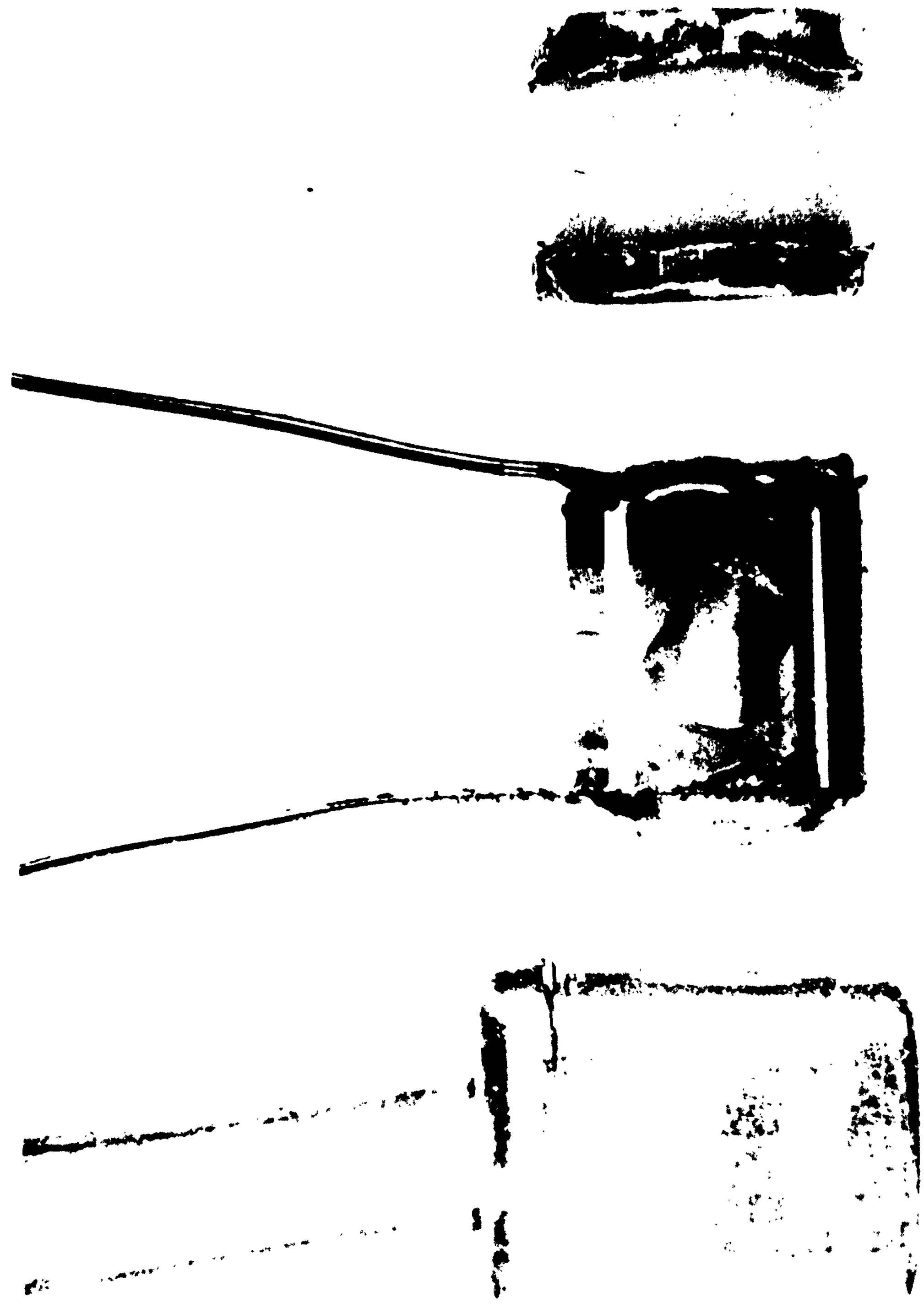


Figure 5
Ultraminiature Crystal Holders
Scale: 10X

FABRICATION METHODS

Quartz Plate Fabrication

In the initial stages, the procedures followed in fabricating ultra-miniature resonators were identical to those employed in the fabrication of normal size resonators. For the lapping and polishing operations, the quartz plate diameter was usually between .200 inch and .300 inch. Final lapping was performed on a Van Coney "pin lap" with meehanite plates and 5 micron aluminum oxide abrasive. Polishing, when necessary, was done on lap plates coated with "Campco" thermoplastic, using cerium oxide as the polishing compound.

After all lapping operations were completed, the plates were reduced to their final diameter. At first an attempt was made to follow the usual procedure of reducing the quartz plate to its final diameter before the final lapping operation is performed, but it proved quite unsatisfactory. Apparently, the difficulty was due to the tendency of the small .100 inch plates to tilt when an uneven distribution of abrasive was encountered. This allowed the quartz plate to come out of its carrier nest and usually resulted in the breakage of most of the lap load.

The diameter reduction was performed on a Gorton tool and cutter grinder equipped with a vacuum chuck and an 850 grit diamond wheel in the following manner:

(1) Approximately 25 (0.003" thick) resonator blanks and one (0.050" thick) end blank are waxed together in the form of a cylindrical loaf.

(2) The end blank is then waxed concentric to an aluminum blank (0.500" dia. x 0.050" thick) and the aluminum blank end of the loaf is chucked on the rotary vacuum spindle of the grinder.

(3) When the diameter has been reduced to the desired value, the loaf is heated and individual blanks are separated, one from another, and cleaned. This method has proved satisfactory down to diameters of 0.050".

Lead Wire Attachment

Figure 6 is a photograph of the system used for making the lead attachment to the resonator blanks. The items pictured in the system are:

1. Bausch and Lomb binocular microscope with 7.5 power lens and 10 power eyepiece (75X).

2. Micro-manipulator (#5060 Brinkmann Instrument) with V shaped wire rack. (VESCO)

3. Vacuum chuck, and attached fume exhaust tubing for holding the resonator blanks. (VESCO)

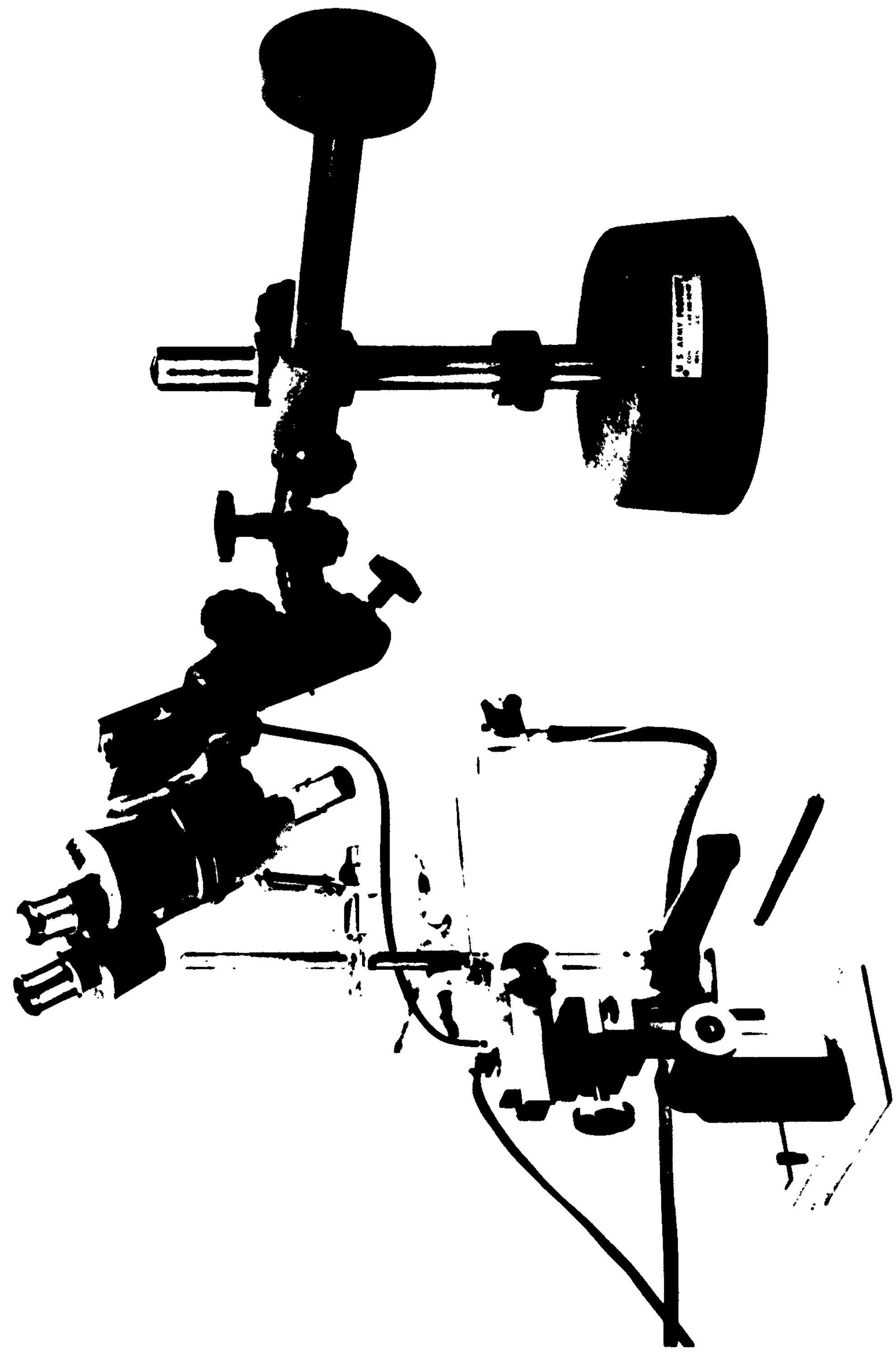


Figure 6
Lead Attachment Apparatus

4. Light source for illumination of resonator blank.

5. Vacuum pick-up tool for use in handling the resonator blanks. (VESCO)

At the outset, it was necessary to choose the form, material, and size of the supporting leads. Wire was chosen as the form because it was readily available in a variety of materials and could be easily handled. Fine silver was selected as the material because of its low electrical resistance and resistance to oxidation. It was necessary to use a wire that was flexible enough to prevent undue strain on the fragile resonator blanks (0.003" thick) so that they were not broken by the forces due to handling the two leads, nor by the firm clamping of the leads in the holder assembly. Wire of 0.003" diameter was found to be sufficiently flexible. The wire was pitted (for better cement adhesion) just prior to use by blasting with fine aluminum oxide abrasive in an S. S. White air abrasive unit.

The procedure for attachment of leads to the resonator blanks is as follows: A blank is picked up with the vacuum tool (which has a Teflon tubing nose) and placed on the vacuum holding chuck (also with a Teflon tubing nose) which holds the blank in a horizontal position. Two or three turns of lead wire are wrapped around one end of the V-shaped wire rack which is affixed to the top end of the micromanipulator. This end is then lightly soldered to hold the wire in place. The wire rack is then squeezed slightly and the lead wire is pulled taut and wrapped around the other end

of the "V" and soldered in place. The spring action of the V-rack keeps the wire taut. The V-rack is positioned so that the wire stretched between the ends is inclined at an angle of approximately 10° to 15° with respect to the plane of the quartz blank. The slight relative inclination of wire with respect to the blank prevents the wire from slipping above or below the blank as it is pressed against the edge of the blank.

A small amount of conductive cement is placed on the lead wire, and the lead wire is then brought into proper position against the edge of the blank by adjusting the micromanipulator.

The lead wire is pulled away from the blank slightly, in order to observe the degree of wetting of the edge of the blank by the cement. Manipulation of the lead is continued until proper wetting has been achieved.

It is important that there be sufficient bonding cement to extend about .005" out onto the face of the crystal plate. This is necessary to insure a good electrical contact with the plating.

Partial curing of the cement is accomplished by passing an electric current through the lead wire by means of the connections at the back of the V-shaped rack. One of the distinct advantages of the method results from the fact that conductive epoxies usually contain a solvent. Curing from the inside out, so to speak, results in a more dense, and thus, stronger joint because the solvent vapors are not trapped within

a cured outer crust such as occurs when the exterior of the cement is heated first.

The epoxy is sufficiently cured in one minute so that the taut lead wire and the attached blank can be moved away from the vacuum chuck. One end of the attached lead wire is cut off as close to the cemented joint as possible, while the other end is left full length. The process is then repeated for attachment of the second lead (see Figure 7).

After the lead wires are attached to the quartz plate, it is placed in an oven to complete the curing of the bonding cement. A normal curing cycle is employed, depending on the type of cement that is being used. For Isochemduct #3.5 this is one hour at 150°C.

Glass Enclosure Preparation

The glass parts are received in finished condition except that the ends are still somewhat rough from the sawing operation. To provide a smooth surface for the metalization and to remove the rough edges, the enclosures are first given a treatment similar to flame polishing. In this case, however, an oven was used rather than a torch. Good results were obtained with an oven temperature of 800°C. At this temperature about 45 seconds is sufficient to round off the sharp edges. Since this is above the softening temperature of the glass, too much time in the oven will result in distorted parts.

The next operation is the application of the platinum metalizing suspension to the ends of the holders. Hanovia #130A (New) Liquid Platinum Alloy was used. This operation was performed by hand with the small number of units made, but a high output technique could be devised for quantity production. In this case, the end of a round toothpick was used to apply the suspension to the glass.

After the metalizing suspension has been applied, the parts are fired to bond the platinum and silver to the glass. Firing temperature is about 600°C for lime glass. It is necessary to allow for a circulation of air through the firing oven to provide sufficient oxygen to oxidize the organic vehicle from the suspension and to allow for the escape of the combustion products. No attempt was made to determine the minimum firing time. Good results were obtained with firing times varying from 30 minutes to one hour.

Before the metalized surface can be tinned, it is necessary to remove the oxide coating. A small hand grinder with a wire brush was used for this purpose. Tinning was performed with either eutectic tin-lead solder (63-37) or indium-silver (90-10) solder and Nalco #14 flux.

Crystal Unit Assembly

The assembly of an ultraminiature crystal unit is performed in three steps: (1) lead attachment, (2) enclosure preparation, and (3) final

assembly and sealing. These steps are illustrated in Figures 7, 8, and 9 respectively. In the sealing operation, a gas heater is employed to supply a stream of hot nitrogen to remove adsorbed moisture from the enclosure. This heater is shown in Figure 10. It consists of 1/4" pyrex glass tubing in the form of a helix, fitted around a 200 watt cartridge heater. The glass coil is connected to a tank of dry nitrogen. The sealing operation is performed in the following manner:

1. A ceramic or glass enclosure, the ends of which have previously been metalized with a fired silver-platinum alloy and tinned with a silver-indium solder, is removed from the alcohol in which it has been stored, and placed in the forceps.

2. Hot nitrogen gas (130°C) is blown through the open ends of the enclosure to evaporate any moisture present.

3. The gas is shut off, and a quartz resonator with leads attached, is inserted and positioned properly within the enclosure. One of the leads is temporarily tacked with solder to one end of the enclosure.

4. The enclosure is then turned such that the end with the free (untacked) lead is facing the heater, and hot nitrogen gas is again directed through the enclosure. Sealing of the enclosure is accomplished by wiping a film of

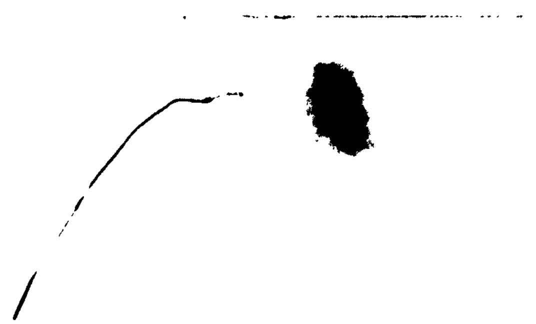


FIGURE 7

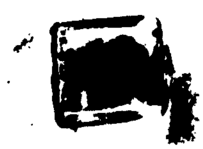


FIGURE 8

FIGURE 9

Figure 10
Nitrogen Heating Coil

solder down the end with the soldering iron. The hot nitrogen jet continues to run during this portion of the operation, and during the subsequent portion, when the enclosure is turned 180° and sealed on the other end.

5. The enclosure is then removed from the forceps, and previously tinned end caps are fitted to the enclosure, and sweat soldered in place.

ELECTRICAL MEASUREMENTS

The impedance of the majority of the ultraminiature resonators was too high to permit their operation in standard crystal impedance meters. For this reason, it was necessary to employ other means of measuring their motional parameters. An admittance bridge was designed for this purpose. The Q of the resonator is determined by measuring the width of its resonance curve and its equivalent resistance is determined by substitution. Figure 11 is a circuit diagram of the bridge. Figure 12 shows the bridge and the associated instruments necessary for its use.

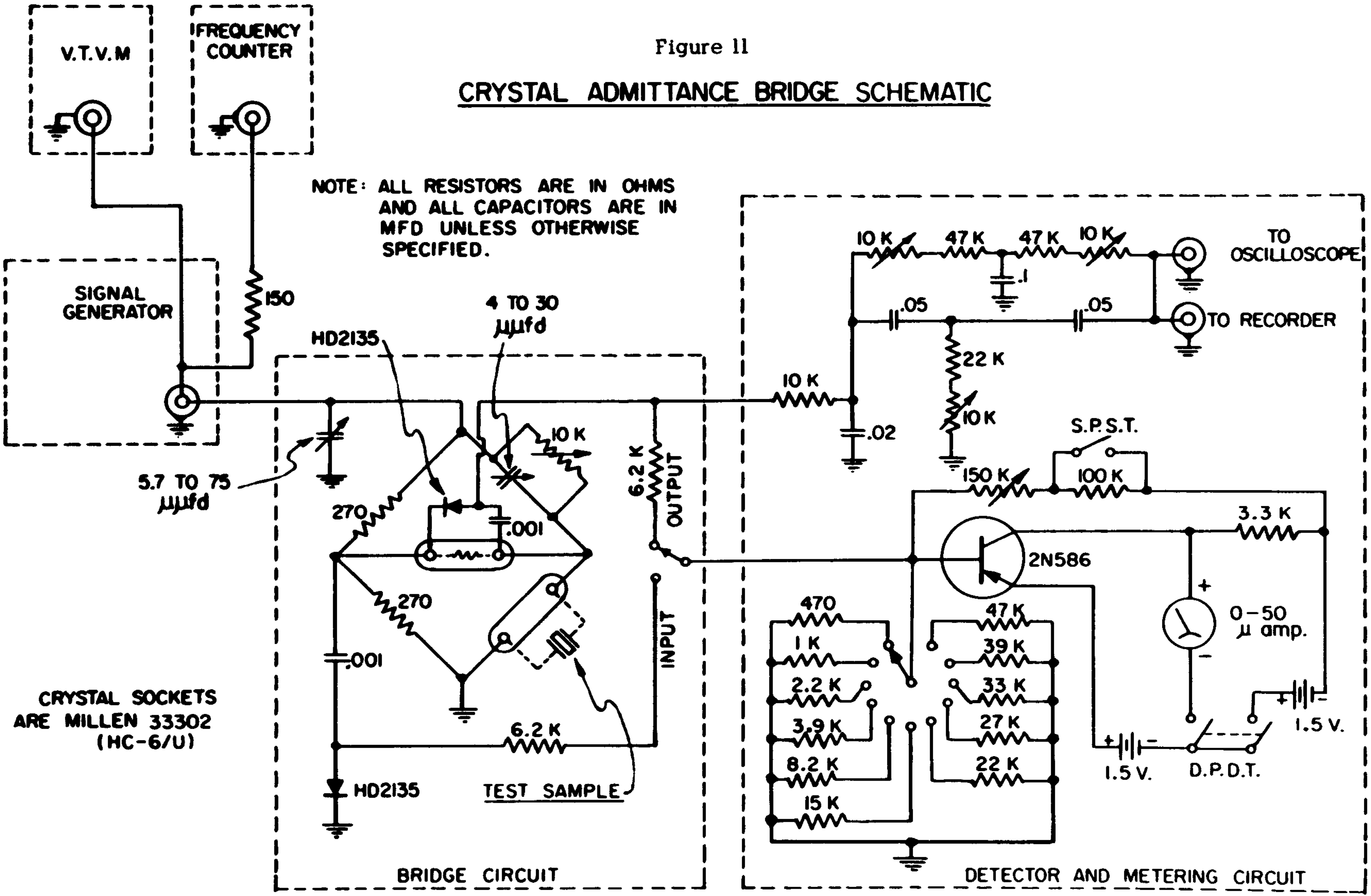
Theory of Operation:

A variable-frequency signal generator (Hewlett-Packard, Model 608A) provides a stable sinusoidal signal for the bridge assembly. The frequency and rms signal voltage of the generator are monitored with a frequency counter (Hewlett-Packard, Model 524B) and vacuum tube voltmeter (Hewlett-Packard, Model 410B), respectively, as shown in the circuit diagram, Figure 11. The signal from the generator is fed to an admittance bridge, one arm of which contains the crystal resonator to be measured. The adjacent bridge arm, used for balancing the bridge, contains a variable capacitance and variable resistance in parallel, which together can be adjusted to provide an impedance equivalent to that of the crystal unit at frequencies slightly below resonance.

Figure 11

CRYSTAL ADMITTANCE BRIDGE SCHEMATIC

NOTE: ALL RESISTORS ARE IN OHMS AND ALL CAPACITORS ARE IN MFD UNLESS OTHERWISE SPECIFIED.



CRYSTAL SOCKETS ARE MILLEN 33302 (HC-6/U)

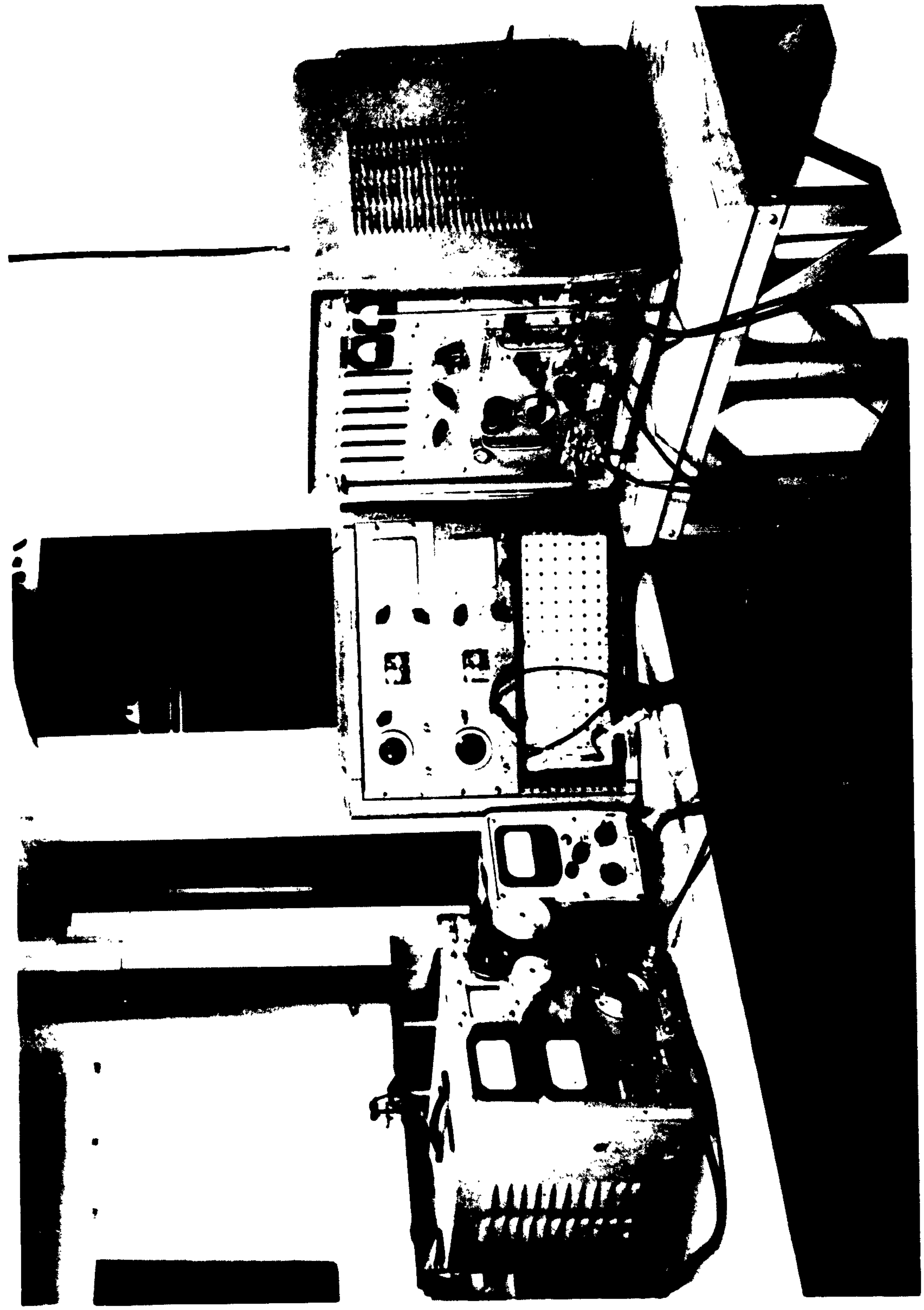


Figure 12
Crystal Admittance Bridge Assembly

As the generator is tuned upward toward a resonance frequency of the crystal unit, with the balancing arm components fixed at arbitrary values, the unbalance of the bridge approaches a maximum as the crystal admittance approaches its maximum value. This unbalance results in current flow through the bridge diode, the 6.2K output resistor and the transistor base resistor. This signal is amplified, and monitored by the ammeter which indicates the current flow between the transistor collector and the emitter.

In order to identify the frequencies associated with the "half-power points" of the crystal resonance curve, the bridge diode must conduct at the same voltage level for the half-power frequencies as it does for the peak frequency. Therefore, with the signal generator set at the peak frequency, its output voltage is increased to a value that will increase the meter current to a value 1.414 times its initial value. Then the generator is detuned until the meter indicates the initial current value. The new frequency, at which the initial meter current is obtained, corresponds to a half-power point of the resonance curve.

Because of the non-linear current-voltage characteristics of some of the circuit elements, the signal voltage at the generator is not directly proportional to the meter current. However, it has been determined that increasing the signal voltage by a factor of 1.200 will increase the meter current by a factor of 1.414 at all frequencies of interest.

Whenever the motional resistance of the resonator under test is less than 270 ohms, a resistance, approximately equal to that of the crystal unit, must be inserted in parallel with the diode in the bridge circuit.

Method Of Operation:

1. Tune the signal generator until a maximum meter reading is indicated. This is close to the resonant frequency of the crystal, (f_r).

2. Detune the signal generator to a frequency that indicates a minimum meter reading.

3. Balance the bridge by varying the capacitor and resistor in the arm not containing the crystal unit. The meter reading should then be zero.

4. Tune the signal generator to the lowest frequency (in the range of interest) at which the current meter reading is a maximum, and note both the signal generator output voltage and maximum meter reading of the assembly. Record the peak frequency (f_p).

5. Increase the signal generator output voltage to 1.200 times that of the previous setting.

6. Detune the signal generator until the meter reading of the assembly output is matched to that noted in Step 4. Record the frequency.

7. Repeat Step 6 by detuning the generator on the opposite side of the resonant peak. Record this frequency.

8. Crystal Q is determined from the following equation:

$$Q = \frac{f_p}{\Delta f}$$

where Δf is the difference between the frequencies recorded in Steps 6 and 7.

BONDING CEMENT EVALUATION

The method used to support the ultraminiature resonators relies heavily on good adhesion of the bonding cement. At the beginning of the program, considerable difficulty was encountered in obtaining both good mechanical strength and electrical conductivity in the bond. To determine which of the readily available conductive cements was most suitable for this application, comparative tests were made of the tensile strength (or adhesive properties) and the electrical conductivity of each.

Tensile strength tests were made by cementing a headed phosphor bronze wire to a smooth glass surface and then measuring the force required to bread the bond. Resistivity measurements were made by cutting a slot about .040" x .040" x 2" in a ceramic block, filling the slot with the bonding material, heat curing the bonding cement, and then measuring the resistance of the strip. The results are listed in Table 4.

TABLE 4

BONDING CEMENT TESTS

Type of Adhesive	Silver Flake Added (% of Total Weight	Solvent	Tensile Strength (lbs/sq. in.)	Resistivity (Ohm cm.)
Bondmaster M640	75%	Cellosolve Solvent	750	1600×10^{-6}
Bondmaster M640	50%	Cellosolve Solvent	1500	4100
DuPont #5504A Silver Conductive Cement	None	None	870	620
Isochemduct #3.5 Silver Conductive Epoxy	None	None	2500	600
Epoxy Products #3012 Silver Conductive Epoxy	None	None	1600	2600
Sodium Silicate	50%	Distilled Water	Too low to measure	740
Hanovia #130A Fired Liquid Platinum Suspension with Tin-Lead Solder	None	None	1340	Not Tested

CONCLUSIONS AND RECOMMENDATIONS

Ultraminiature resonators can be produced with sufficiently high Q values to permit their use as frequency controlling devices over a wide range of frequencies. Equivalent resistance values can be achieved, at least at the higher frequencies, which are low enough to make the use of impedance transformation unnecessary. Drive levels for these resonators should be as low as possible because of the very small size of the ultraminiature quartz plate. As the resonant frequency required increases, the feasibility of employing an ultraminiature resonator also increases. Above 100 MC, the difference in performance between ultraminiature resonators and ordinary quartz resonators ceases to be very significant. Above 200 MC, the difference would probably disappear. At the lower frequencies, however, the feasibility of such small resonators becomes questionable.

Additional development will be necessary if glass enclosures of the type used in this program are to be employed for ultraminiature resonator applications. The metal holders that were tested are quite satisfactory, but are somewhat larger than required for .100 inch resonator plates.

IDENTIFICATION OF KEY ENGINEERING AND TECHNICAL PERSONNEL

The personnel listed below contributed to various phases of the program during the total contract period:

ENGINEERS	Hours
Deininger, J. G.	826
Lavan, J. T.	461
Stringe, J. W.	2091
Tyler, L. A.	362
Bennett, R. E.	232
Total Engineering Time	3972

TECHNICIANS	
Barco, D. G.	59-1/2
Bishop, D. C.	87
Blomgren, T. A.	658-1/2
Gross, G. A.	86-1/2
Leide, T. A.	2504
Oetting, R. L.	143
Papa, I.	280-1/2
Pechukas, V.	279-1/2
Pesek, B.	94
Zamet, N. A.	180-1/2
Total Technician Time	8345

AD DIV.

Victor Electronic Systems Company, Victor Comptometer Corporation, Chicago, Illinois, ULTRAMINIATURE QUARTZ CRYSTAL UNITS by Len A. Tyler, Final Report, 15 June 1960 - 14 October 1962, 46 p. incl. 11 figs.
Contract DA-36-039-SC-85348 Unclassified Report

Ultraminiature quartz resonators meeting the minimum Q requirement of 10,000 were fabricated at frequencies from below 9 MC to above 150 MC. Quartz plates as small as .100 inch in diameter gave satisfactory results over most of this frequency range. Contouring was necessary below 25 MC, but plane-parallel plates proved satisfactory above this frequency.

Both ceramic and glass enclosures were developed for these resonators. The overall volume of these enclosures was less than .002 cubic inches. Metal holders obtained from a commercial source were also used. These holders had a volume of approximately .006 cubic inches.

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1. Ultraminiature quartz crystal units, design and development.
2. Glass enclosures design and development.

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This contract is supervised by the Solid State & Frequency Control Division, Electronic Components Department, USAELRDL, Fort Monmouth, New Jersey. For further technical information, contact the Project Engineer, Mr. Marvin Bernstein, Telephone 535-1978 (New Jersey Area Code 201).